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PETROLOGY OF No. 3 TUNNEL, KIEWA HYDRO-ELECTRIC SCHEME, BOGONG, VICTORIA

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Abstract

The rocks of No. 3 Tunnel, Bogong, consist of mesocratic granodiorite intruded into pre-existing regional metamorphic rocks (?Ordovician), and injected by a group of leucocratic and melanocratic dyke rocks including granodiorite aplite, dioritic lamprophyres and monchiquite. Metasomatism and shear post-dated the dyke intrusions and resulted in the introduction of secondary sulphides, the formation of epidote, zoisite and chlorite in parts of nearly all the rock types present, the formation of pug seam in parts, shear zones and slickensided joint planes in others, and the introduction of calcite and quartz veins, more particularly in the shear zones.

Introduction

The Bogong area is 150 miles north-east of Melbourne. No. 3 Tunnel, five miles south-west of Mt. Bogong, was made by the State Electricity Commission of Victoria, in connection with the Kiewa Hydro-Electric Scheme. The tunnel is 16 feet in diameter and approximately one mile long, extending from the Junction Dam (Lake Guy) in the south, to Clover Flat in the north (Fig. 1).

The rocks comprising the walls of No. 3 Tunnel were inspected by Professor E. S. Hills and the author in November, 1941. Professor Hills prepared the field notes.

Grey granodiorite forms the major part of the tunnel walls and roof, and is encountered more particularly at the northern end of the tunnel, where for a distance extending between 3,700 and 4,400 feet from the tunnel opening at the southern end (see Fig. 2), the rock is almost exclusively grey granodiorite. Red, pink and greenish-coloured granodiorite, in part pyritised and strongly metasomatised, occurs frequently in narrow zones between 1,100 and 3,700 feet from the south end of the tunnel.

From the tunnel entrance at the southern end to 1,000 feet northerly, the principal features of the granodiorite are its xenolith content and the presence of acid and basic schlieren in various stages of reconstitution. Xenoliths and clots of ferromagnesian minerals are also prominent in the grey granodiorite in the vicinity of the surge tank (see Fig. 2).

Numerous melanocratic, lamprophyric dykes and leucocratic, acid dykes and veins cut the granodiorite. They occur principally over a length of 3,500 feet from the south end of the tunnel.*

Quartz veins were noted as follows—(1) cutting a pug seam in the granodiorite at 820 feet, (2) in a spessartite dyke at 1,100 feet, (3) in grey granodiorite at 1,425 feet and (4) in pink granodiorite at 1,875 feet.

Slickensided shear planes are evident in the granodiorite at 2,205, 2,285 and 2,335 feet.

The locations of dykes, veins, zones of shear and zones where metasomatism has occurred, are indicated in Fig. 2. Calcite veins are associated with some of the metasomatised zones.

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* all distances in feet are measured from the south end of the tunnel.

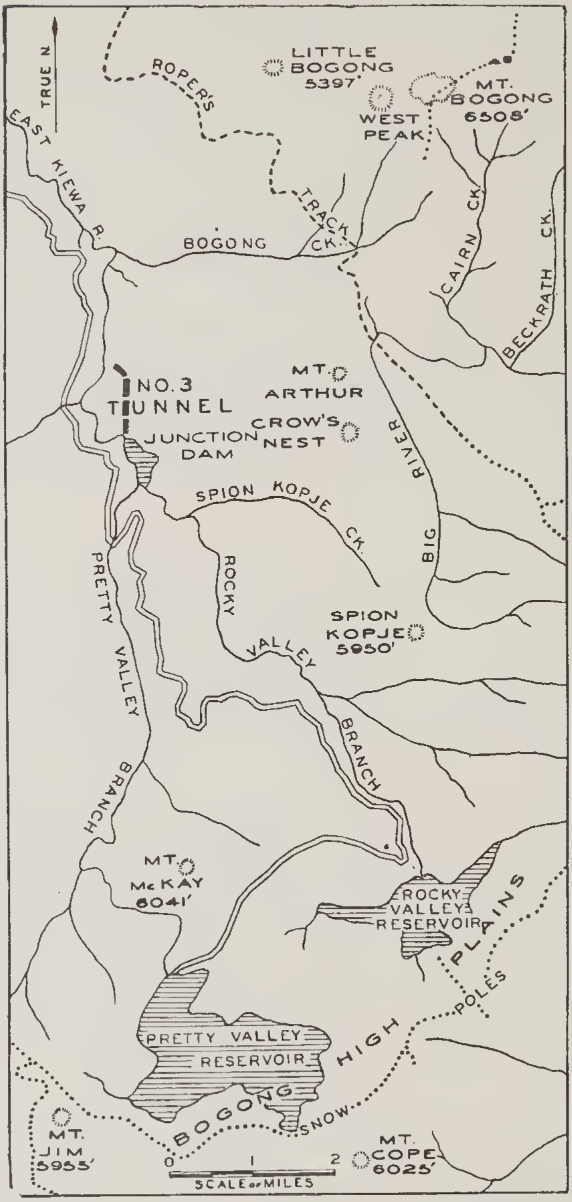

Fig. 1. Sketch locality map, to show site of No. 3 Tunnel, Kiewa river, Bogong. (Based on plan of Kiewa Hydro-Electric Scheme, prepared by the State Electricity Commission of Victoria).

The Granodiorite

Nature of the Granodiorite

The granodiorite is a medium, even-grained rock of light to darker grey colour, with occasional bladed crystals of hornblende up to 15 mm. long and 3 mm. across. The major constituents are quartz, oligoclase in excess of orthoclase (see Table 1), and biotite in excess of hornblende. The accessory minerals are apatite, zircon, orthite and iron ore minerals. A few of the apatite crystals possess coloured pleochroic cores.

MICROMETRIC ANALYSES

Micrometric analyses of the several colour and textural varieties of the granodiorite from No. 3 Tunnel at Bogong, show variable percentages (by volume) of the minerals present.

TABLE 1

	I	II	III	IV	V	VI	VII	VIII	IX	X
Quartz.. ..	25·5	28·5	30·9	32·5	31·3	44·2	16·9	24·9	28·7	25·1
Biotite.. ..	9·6	6·9	9·1	13·1	7·3	20·9	20·4	12·3	12·2	16·3
Orthoclase ..	19·9	12·8	18·0	14·5	16·1	—	27·0	8·4	17·5	15·5
Plagioclase ..	43·3	48·7	39·8	37·4	41·1	14·8	30·9	49·7	37·8	37·3
Hornblende ..	1·3	2·1	0·6	0·1	1·0	—	1·6	3·5	2·2	1·0
Cordierite and Muscovite ..	—	—	—	—	—	17·9	—	—	—	—
Accessories ..	0·4	1·0	1·6*	2·4*	3·2*	2·2″	3·2	1·2	1·6	4·8
Ratio O : P ..	1 : 2·2	1 : 3·8	1 : 2·2	1 : 2·6	1 : 2·5	—	1 : 1·1	1 : 5·9	1 : 2·1	1 : 2·4
Total ferro-magnesian minerals and accessories ..	11·3	10·0	11·3	15·6	11·5	23·1	25·2	17·0	16·0	22·1

* = with epidote ; ″ = with sillimanite and diopside.

I—normal grey granodiorite, 2,095 feet.
II—normal grey granodiorite, 4,015 feet.
III—pale pink granodiorite, average of four samples from different parts of the tunnel.
IV—pale pink to greenish-coloured granodiorite, average of two samples.
V—greenish-grey granodiorite, 3,455 feet.
VI—basic schlieren, 615 feet.
VII—granitised xenolith, 4,323 feet.
VIII—granitised xenolith, 870 feet.
IX—granodiorite at contacts of xenoliths, average of three samples.
X—granodiorite at contacts with melanocratic dykes, average of two samples.

In the metasomatised granodiorite (Table 1, Nos. III to V), chlorite is included in the biotite percentages. The ratio of plagioclase to orthoclase felspar throughout the granodiorite samples in Table 1 is in keeping with Hatch's 2 : 1 ratio for typical granodiorite rock.

The higher combined percentage values for ferromagnesian and accessory minerals for some varieties of the granodiorite, are due to added constituents from contamination by assimilation. This is particularly marked in the micrometric analysis of granodiorite in contact with xenoliths (Table 1, No. IX); the trend can be observed by comparison of Nos. I and II with Nos. VII, VIII and IX in Table 1. The greater content of ferromagnesian plus accessory minerals in some of the metasomatised portions of the granodiorite (Table 1, Nos. III to V), is also due to previous contamination by assimilation. The accessory mineral percentages of these portions (Table 1, Nos. III to V) of the granodiorite include calcite, epidote and orthite, in addition to the normal primary accessories zircon, apatite and iron ore minerals. In the basic schlieren (Table 1, No. VI), the accessory minerals are largely sillimanite, diopside and zircon.

The increased quartz content in the metasomatised portions of the granodiorite (Table 1, Nos. III to V), averages 4·5 per cent and points to the metasomatic solutions being silica-bearing. Except in the basic schlieren, hornblende is persistent, although generally of small amount, throughout the granodiorite varieties and contained xenoliths. Like biotite, the hornblende tends to occur in greater amounts in contaminated portions.

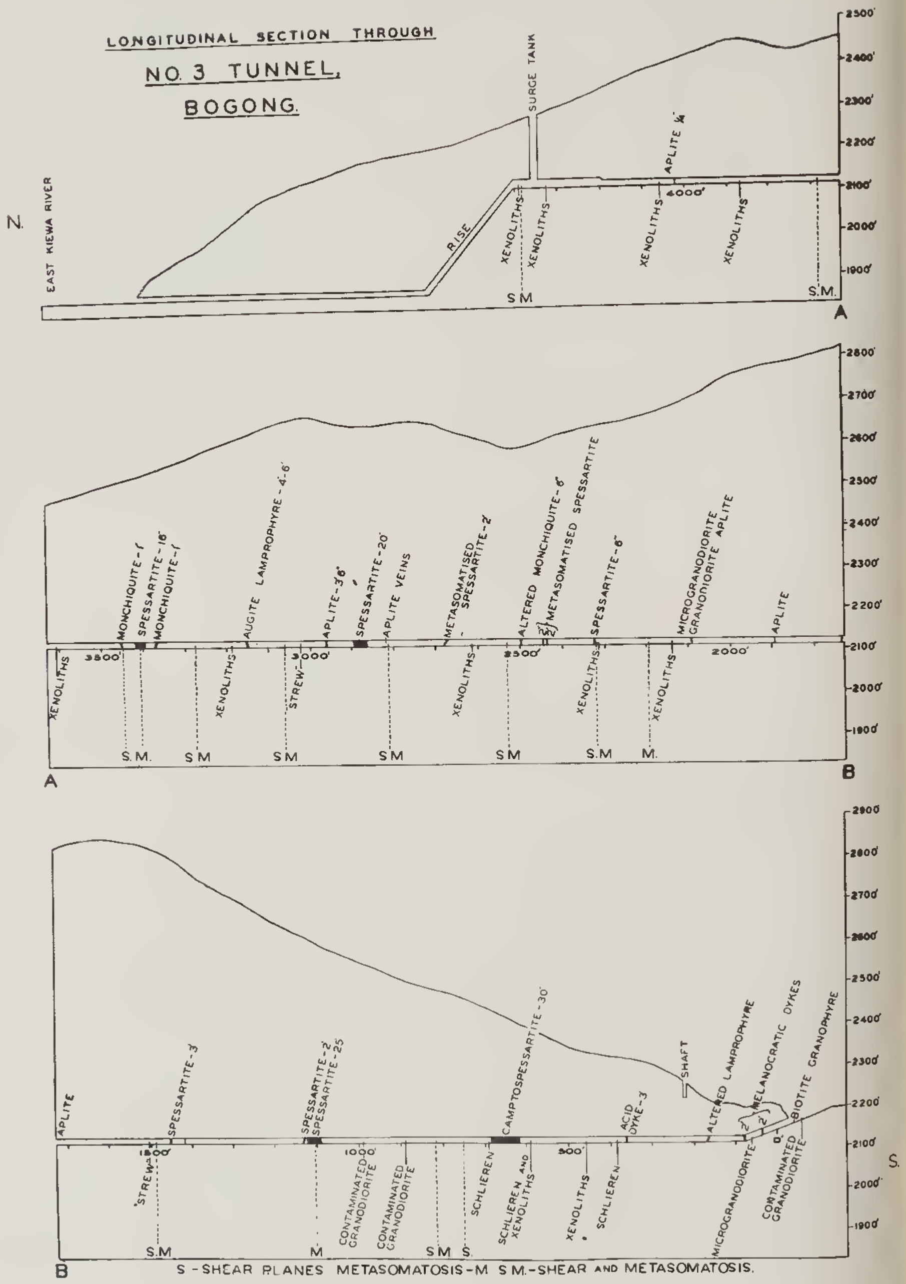

Fig. 2.

Longitudinal section from North to South through No. 3 Tunnel, Kiewa river, Bogong. (Based on section prepared by State Electricity Commission of Victoria). Showing locations of dykes and veins, schlieren and xenoliths, and planes and zones of shear and metasomatism. Figures arranged along vertical lines indicate heights above sea level. Divisions arranged along floor of tunnel indicate distances in hundreds of feet from the southern end.

HEAVY MINERAL ANALYSES OF THE GRANODIORITE AND XENOLITHS

The index numbers (Table 2) of the several varieties of the granodiorite and its contained xenoliths and schlieren, represent the weight percent of minerals having a specific gravity greater than that of bromoform (sp. gr. = 2·88) in which they were separated from the light minerals.

TABLE 2

Variety	Distance from south end of Tunnel	Index Number	Variation Factor
Pinkish-green granodiorite . .	3,065 feet	4·4	M
Normal grey granodiorite . .	4,115 feet	9·5	P
Red granodiorite	2,105 feet	10·6	M
Normal grey granodiorite . .	4,341 feet	11·4	P
Pinkish-green granodiorite . .	2,535 feet	12·0	M
Normal grey granodiorite . .	3,015 feet	12·1	P
Pale pink granodiorite	1,695 feet	14·0	M
Granitised xenolith	870 feet	21·8	C
Basic schlieren	615 feet	31·8	C

The variation factor M connotes metasomatised varieties, P refers to the fact that most of the mineral species in the heavy residues are primary constituents of the normal granodiorite, and C signifies contamination.

Two principal factors affecting index number variation are (a) the degree of dissemination and 'strewing' of contamination products, and (b) the amount of mineral matter newly introduced during metasomatism. Variations in the index numbers from 9·5 to 12·1 in the normal grey granodiorite, are ascribed to the effects of contamination. The variation, however, is not great when compared with other Victorian granodiorites, which have an average index number of approximately 13, with values over 15 indicating considerable contamination (Baker, 1942). On this basis, the granodiorite in No. 3 Tunnel, Bogong, has not been subjected to extensive contamination by assimilation. Metasomatism, however, has played some considerable part in affecting the index numbers, the variation being from 4·4 to 14·0. The general effect has been to lower the index numbers, largely as a result of bleaching of the ferromagnesian minerals in parts, with the concomitant formation of products of lower specific gravity. Index numbers larger than those for the normal grey granodiorite, are due in the metasomatised portions, to the introduction of secondary sulphide minerals.

The mineral species in the heavy mineral assemblages throughout the granodiorite, remain much the same for the several varieties investigated, the main variant being the amounts of each present.

Of the various minerals in the heavy mineral assemblages, magnetite is abundant throughout and considerably in excess of ilmenite. Biotite is the most abundant mineral both throughout the assemblages and in any one heavy mineral suite, being greatly in excess of hornblende in all instances. The amounts of chlorite and secondary white mica vary from assemblage to assemblage according to the degree of metasomatism suffered by the granodiorite.

Minerals introduced by secondary solutions are pyrite and pyrrhotite, usually in small quantities. Minerals formed by the metasomatism of pre-existing minerals are epidote and zoisite, which vary considerably in amount in the assemblages.

Among the primary accessory minerals, apatite is more common in the contaminated portions of the granodiorite. Occasional stumpy, prismatic crystals of apatite with coloured cores, are pleochroic from purple to brown. Zircon is rather more common than apatite in the less contaminated granodiorite, occurring usually as clear, colourless crystals, rarely as zoned crystals, and sometimes as crystals containing a few minute inclusions. The zircon crystals are usually small and sometimes show acicular habit. Sphene and orthite are rare in the heavy mineral assemblages. Occasional sillimanite and diopside are represented in the heavy mineral assemblage of the basic schlieren, which also contains very rare, pale yellow crystals of zircon, a variety not found in the granodiorite.

The heavy mineral assemblage of the granodiorite from No. 3 Tunnel, Bogong, generally resembles that of the ' Tawonga ' granodiorite (Baker, 1942). The term ' Tawonga ' refers to granodiorite sampled by Mr. D. McCance, from outcrops south of No. 3 Tunnel, the township of Tawonga being some 20 miles to the north-west. Now that this area has been opened up by the State Electricity Commission of Victoria, a more precise location can be rendered for the ' Tawonga ' sample. The sample formerly examined (labelled ' Tawonga ') came from near the snow poles, three quarters of a mile east of the projected boundary of the Rocky Valley Reservoir (see Fig. 1), approximately 8 miles south-east of No. 3 Tunnel. The high index number (18.3) for the ' Tawonga ' sample, is evidently a result of more extensive contamination than obtained in the No. 3 Tunnel granodiorite. Like the granodiorite from No. 3 Tunnel, Bogong, the ' Tawonga ' occurrence has been similarly partially metasomatised.

VARIATIONS IN THE GRANODIORITE

The non-uniformity of the granodiorite is due to two principal factors (a) contamination by assimilation, and (b) metasomatism. (a) The granodiorite is contaminated in the neighbourhood of many of the xenoliths, and on a larger scale near the south end of the tunnel, where basic schlieren are common.

All xenoliths observed have been granitised, some more so than others, but all to such a degree that no palimpsest structures are preserved in any of them. The more granitised of the xenoliths contain orthoclase, orthoclase-perthite and a little microcline, which together are often in excess of plagioclase. Many of the felspars are poikilitic. Some of the plagioclase crystals occur as jacketed laths (cloudy centres with clear rims) in xenoliths having plagioclase in excess of orthoclase. Quartz is sometimes developed in the xenoliths as pools in optical continuity. Orthite and apatite with coloured pleochroic cores also occur in the xenoliths, where they have been generated during processes of reconstitution. These are regarded as contamination accessory minerals where found in the granodiorite itself.

A two-way migration of mineral constituents has occurred between the xenoliths and the granodiorite magma, the xenoliths mainly become enriched in quartz and potash felspar, the granodiorite in biotite, hornblende and xenocrysts of orthite and apatite with coloured cores.

Basic schlieren are especially well developed in the granodiorite of the tunnel between 585 and 695 feet. Here they dip 30° to the north-east. They are associated with occasional acid schlieren that consists mainly of quartz and oligoclase. In the basic schlieren, well-marked bands of quartz and orthoclase, with some orthoclase-perthite alternate with bands of biotite and accessory apatite and zircon. In parts, as at 585 feet, large felspars up to $1\frac{1}{2}$ inches across have been formed in the schlieren. Sillimanite, cordierite, muscovite and strained quartz crystals in the schlieren, are original minerals of the incorporated country rock. With more advanced reconstitution of the basic schlieren (Pl. XVIII D), sillimanite has been made over to aluminosilicates (felspar, etc.) crystallising from the granodiorite, but cordierite and muscovite persist into later stages. At the same time, oligoclase becomes dominant over orthoclase, and quartz is generally sutured although non-strained.

(b) Paulopost alteration of the grey granodiorite is associated with narrow but numerous shear zones. As a result of metasomatism, pale pink, deeper pink to red, pinkish- to greenish-coloured and less frequently greenish-grey to dirty white varieties have been developed in the granodiorite.

Alteration (Pl. XVIII C) is most pronounced along shear planes and narrow zones, and varies from a fraction of an inch to a few feet across. The greenish colour of parts of the altered granodiorite is due to the prevalence of chlorite and epidote. The red colour is due to microscopically thin films of hematite, the pink to hematite and limonite. Dirty white varieties have resulted from complete bleaching effects by the more intensely active metasomatic solutions, accompanied by removal of dissolved ions during propylitisation.

In all these varieties, oligoclase remains in excess of orthoclase(see Table 1), but the oligoclase becomes more rapidly altered than the orthoclase. Thus in the pale pink portions, microcline and orthoclase-perthite remain clear, but the plagioclase felspars have been much altered to muscovite and zoisite. In deeper pink to red portions, both orthoclase and plagioclase felspars are much altered and reddish in colour due to secondary hematite films. In light greenish-grey portions, both types of felspar have been profoundly altered.

Both ferriferous and non-ferriferous varieties of epidote occur in the metasomatised granodiorite, the less iron-rich varieties grading into zoisite. The conversion of biotite to chlorite increases with stronger metasomatism, epidote being formed along the cleavage traces, while rods of iron ore minerals and rosettes of sphene become more prominent. Where metasomatic solutions have been most active, the biotite in the granodiorite has been completely bleached and abundant leucoxene developed along cleavage planes. Hornblende was rapidly affected by the metasomatic solutions, because even in portions least altered by metasomatism, the hornblende is represented by clots composed of epidote-zoisite-chlorite and a little biotite. In the more highly metasomatised portions of the granodiorite, some of the quartz shows strain polarisation due to accompanying shear.

The Dyke Rocks

Approximately forty dykes and veins occur between the incline at the south end of No. 3 Tunnel and the surge tank nearly 4,400 feet to the north (see Fig. 2). The intrusions form part of the Bogong dyke swarm of post-granodiorite age. They were injected during a period of tension as 'flash intrusions', causing strain shadows to be formed in the minerals of the granodiorite adjacent to the walls.

The dykes all occur as single intrusions. They comprise a series of calcic minor injections grading from leucocratic acid types of the aplite family, through melanocratic intermediate to basic lamprophyric types (see Table 3) characterised by hornblende. The lamprophyres are the most numerous of the dykes in the tunnel. All of the dykes cut through the granodiorite with sharply-marked contacts.

Size and Disposition of the Dykes

The lamprophyric dykes are variable in width (see Fig. 2), but like many lamprophyres throughout the world (Brögger, 1894, p. 24; Read, 1926; Reynolds, 1931; Richey, 1939, p. 405; Poitevin and Cooke, 1946, p. 88), they are relatively narrow, ranging from $1\frac{1}{2}$ inches to thirty feet across.

The walls of the dykes are vertical or steeply inclined. Dips vary from 85° west of north and 70° to 75° east of north, to 85° west of south. Fourteen of the dykes strike approximately W30°N, two W85°N, two W15°S and four

W35°S. Shear zones, pug seams and schlieren in the granodiorite, strike generally north-westerly, i.e., in the same direction as the majority of the dykes. It is deduced from the parallelism of most dykes, shear zones, joint planes, etc. in this area, that two principal sets of planes of weakness have controlled the directions of injection of the dyke rocks, the main emphasis being on the W30°N set.

AGE OF THE DYKES

Beyond the fact that the dykes cut through the Bogong granodiorite, no direct evidence of age is available. Since none of the dykes intersect and composite dykes are unrepresented, the age relationships cannot be stated for the leucocratic and melanocratic dykes. The monchiquites show no apparent connection with the Older Volcanic (Tertiary) basalt flows of the Bogong High Plains, and are related petrologically to the other melanocratic members of the Bogong dyke swarm. The dykes were injected prior to a phase of sulphide formation that accompanied metasomatic alteration by invading mineral-bearing solutions, and were followed by the injection of quartz and calcite veins.

PETROLOGICAL TYPES OF THE DYKES AND VEINS

Types of dyke rocks found in No. 3 Tunnel, Bogong, are set out in Table 3. The list includes two dyke rocks collected among material dumped from the tunnel excavations (see * in Table 3), but not actually located in the tunnel walls, parts of which were heavily timbered and parts exceedingly dusty from blasting operations.

TABLE 3

	Type of Dyke Rock	Principal Ferromagnesian Minerals present
LEUCOCRATES	Granodiorite Aplite Microgranodiorite	
	Biotite Granophyre Granodiorite Porphyrite*	Biotite
MELANOCRATES	*Dioritic Lamprophyres* Spessartite (Hornblende Lamprophyre)—porphyritic and microcrystalline varieties, some unaltered, others metasomatised	Hornblende
	Camptospessartite Augite Lamprophyre (one example*) Camptonite (metasomatised)	Hornblende, some augite and pseudomorphs after olivine
	Monchiquite	Pale purple augite, common augite and pseudomorphs after olivine

The dyke rocks listed in Table 3 are not confined to the precincts of No. 3 Tunnel. Preliminary surface field work (unpublished) carried out by Mr. M. A. Condon for the State Electricity Commission, and bore cores from the neighbourhood of the Hydro-Electric Scheme in the Bogong region, have revealed occurrences that are allied to the acid and basic dykes encountered in the tunnel. In addition, samples supplied by Mr. D. McCance, show that dyke rock similar to the dyke met at 1,120 feet in the tunnel, occurs near the summit of Mt. Bogong, and an allied type occurs at West Peak (see Fig. 1) on the Bogong Ridge.

THE LEUCOCRATES

Quartz Veins. Quartz veins are uncommon and narrow in No. 3 Tunnel. They cut through metasomatised granodiorite, are associated with a few of the shear zones and pug seams, and have been injected along some of the dyke-granodiorite contacts. Quartz has also been introduced into metasomatised portions of some of the dyke rocks, as at 2,265 feet, where small cavities, first lined with quartz crystals, were later infilled with calcite containing pyrite cubes. The quartz veins are of massive reef quartz containing a little pyrite and pyrrhotite, but no gold.

Granodiorite Aplite. Injections of granodiorite aplite form the more common of the leucocratic dykes and veins, varying in width from ¼ inch to 3 feet 6 inches. They occur at 1,735, 1,895, 2,085, 2,815, 2,965 and 4,025 feet in the tunnel. At 4,025 feet, an aplite veinlet ¼ inch across, is flat-lying and offset 18 inches at its southern end. This displacement occurred during the subsequent development of vertical shear zones. Dark greenish-grey stringers of quartz occasionally traverse the central portions of the aplite dykes. They were introduced during subsequent metasomatism, rather than from the magma penecontemporaneously with aplite injection.

The granodiorite aplite is dense and has a fine-grained saccharoidal texture. The principal minerals are quartz, oligoclase in excess of orthoclase, and a small amount of pyrite and non-ferriferous epidote. The rock is typically deep pink in colour, due to thin films of hematite along cracks and cleavages in the principal minerals. As in metasomatised portions of the granodiorite, the hematite seems to be a product of autopneumatolysis. Ferromagnesian minerals are typically absent from the granodiorite aplite.

Leucocratic Vein. A leucocratic vein, consisting largely of fine-grained quartz and felspar (Plate XVIIIB), intrudes contaminated granodiorite at the incline, southern entrance to the tunnel. Small veinlets of this rock pass out along narrow shear planes in the contaminated granodiorite. The vein has picked up some of the constituents of the coarser-grained contaminated granodiorite, and the xenocrysts so formed have been drawn out along flow directions in the vein rock.

Microgranodiorite. Microgranodiorite occurs near the tunnel entrance (south end) and at 2,125 feet (Fig. 2). It is essentially the same as the pink and pinkish-green metasomatised portions of the granodiorite, except that the grain size is approximately one third that of the granodiorite. The rock contains some microcline, oligoclase in excess of orthoclase, and quartz. Chlorite and epidote are well represented.

Biotite Granophyre. Biotite granophyre from the incline, southern entrance to the tunnel (Fig. 2) is a grey, porphyritic rock composed of phenocrysts of biotite and occasional altered, zoned oligoclase in a fine-grained groundmass of quartz, orthoclase, biotite shreds, epidote, zoisite and muscovite. Micrographic intergrowths are pronounced in the groundmass.

Granodiorite Porphyrite. A pink-coloured porphyritic rock, found cutting blocks of granodiorite in the dump from the tunnel excavations, is regarded as granodiorite porphyrite.

The phenocrysts consist of clear oligoclase in excess of orthoclase-perthite, and turbid plagioclase replaced by secondary muscovite and epidote. Biotite phenocrysts are as numerous as, but much smaller than the felspar phenocrysts.

The groundmass is a fine-grained aggregate of quartz, oligoclase dominant over orthoclase, chlorite and biotite. The rock, like most others from No. 3 Tunnel, has been subjected to some metasomatism.

THE MELANOCRATES

Many of the melanocratic dyke rocks are little altered, although nearly all are sulphide-bearing. Several have been subjected to varying degrees of metasomatism, as in comparable dyke rocks described by Junner (1921), by Broadhurst and Campbell (1932) and by Thomas (1947). A few are so much altered that they can only be referred to as altered lamprophyres.

The most frequent and wider of the melanocratic dykes are varieties of dioritic lamprophyre, of which hornblende spessartite is the most common. Three of the more basic lamprophyric dykes are felspar-free and referable to monchiquite.

Textural variations are well-marked in the melanocrates. Among the dioritic lamprophyres, porphyritic types occur at 675, 1,455, 2,235, 2,435, 2,445 and 3,155 feet (see Fig. 2). Microporphyritic types occur at 1,135 and 3,415 feet, fine to medium, even-grained, non-porphyritic types at 1,120, 2,665, and 2,885 feet. Dykes of monchiquite occur at 2,495, 3,365 and 3,455 feet, and are microporphyritic.

The grain size of the groundmass varies. It is microcrystalline in all of the monchiquite dykes and in the dioritic lamprophyres from 1,135, 2,325, 2,435, 2,445, 2,665 and 3,155 feet, as well as at the edges of dykes at 2,885, and 3,415 feet. The groundmass is fine-grained in lamprophyres at 675 and 1,455 feet, and coarser (fine- to medium-grained) in dykes at 1,120 and 3,415 feet and in the centre of the 20 feet wide dyke at 2,885.

The mode of intrusion of the melanocratic dykes was by forcible injection, cracks opening ahead of the molten rock as it flashed through the already consolidated granodiorite. This is indicated to some extent at the edge of a metasomatised camptonitic dyke, part of which is illustrated in Plate XIX. The edge of the dyke (dark-coloured portion in Plate XIX) is sharply marked, zoned felspars and other crystals in the granodiorite at the contact have been cut clean across, and a small veinlet of dyke rock passes out along a shear zone in the granodiorite. The minerals of the granodiorite along this shear zone have been fractured and granulated. Granulation is most marked near the outer end of the veinlet ; the shear zone, which forms an acute angle with the edge of the dyke, dies out within a distance of a little over one inch. Many of the minerals immediately adjacent to the more strongly marked zone of shear, show mortar structure resulting from granulation of crystal edges.

Dioritic Lamprophyres

Spessartite. Dykes referable to spessartite range in width from 6 inches to 25 feet. They are principally hornblende spessartites, composed essentially of hornblende and plagioclase (oligoclase-andesine), usually as phenocrysts, sometimes with a small amount of quartz. The hornblende is characteristically the greenish to greenish-brown variety typical of intermediate rocks. Common augite is occasionally present.

The term ' spessartite ' is used for these dyke rocks, since ' microdiorite ' can be ruled out by their mineralogical character and because they are associated with granodiorite aplite, an association that is not characteristic of ' microdiorite ' (Hatch and Wells, 1937, p. 252). The spessartites show no content of orthoclase, a felspar that is notably present in most, and probably all diorites (Hatch and Wells, 1937, p. 118) ; moreover, diorites have granitic texture, whereas these dyke rocks are lamprophyric.

Typical spessartite occurs in the tunnel at 1,120, 2,665 and 2,885 feet, microporphyritic spessartite at 1,135 and 3,415 feet. Porphyritic spessartite occurs at 1,455, 2,325, 2,435 and 2,445 feet.

The spessartite is fine-grained, greenish-grey in colour and contains secondary sulphides, mainly pyrite. The principal minerals are green hornblende and oligoclase-andesine. Iron ore minerals are abundant, biotite is rare and always subordinate to hornblende. Interstitial quartz appears in occasional micrographic intergrowths. The principal secondary minerals are epidote, zoisite, chlorite and pyrite associated with a little calcite. Abundant, needle-like crystals of apatite are sometimes scattered, sub-parallel or en echelon in the groundmass.

Metasomatism of the spessartite has developed ocellar texture in parts of some dykes. This is due to the formation of small ocelli (Smith, 1933 and Read, 1926, p. 429) which resemble phenocrysts in the hand specimen, imparting to the rock a 'pseudo-porphyritic' texture. The ocelli consist of introduced calcite and quartz carrying cubes of pyrite. Metasomatically altered spessartite consists almost entirely of calcite, chlorite, quartz and muscovite replacing the original minerals. Small clots and crystals of yellowish colour are siderite.

The edges of some of the dykes were subjected to rapid chilling, as observed from comparison of thin sections from the centre and southern edge of the 20 feet wide spessartite dyke at 2,885 feet. The edge is much finer-grained and has rather more basic plagioclase (andesine-labradorite) than central portions.

Microporphyritic spessartite (dykes at 1,135 and 3,415 feet), contains sporadic microphenocrysts of basic plagioclase in a finer-grained groundmass of plagioclase laths, ilmenite grains and patches of chloritic matter (in the 2 feet wide dyke at 1,135 feet). At 3,415 feet, where the spessartite occurs as a dyke 16 feet wide, samples taken at two feet intervals across the dyke, revealed on sectioning that the rock is generally fine-grained but has much denser edges. Away from the edges, microphenocrysts and quartz pools are present ; the quartz has been secondarily introduced. In the metasomatised portions of this dyke, epidote and chlorite have replaced hornblende, and several of the felspars have saussuritised cores enveloped in jackets of clear plagioclase. Newly introduced minerals are quartz, calcite and pyrite.

Porphyritic Spessartite. Porphyritic spessartites are sometimes regarded as camptonite, but camptonite is usually more basic and contains titanaugite, a mineral not represented in this particular group of the Bogong melanocrates. The more metasomatised members (e.g. at 2,445 feet) might have been originally camptonitic, but alteration is too profound for accurate determination of the original character of the augite.

Porphyritic spessartite at 1,455 feet contains pink phenocrysts of saussuritised felspars stained with hematite and frequently outlined by partially developed rims of epidote. In other porphyritic spessartites, the felspar phenocrysts have been calcified. The phenocrysts occur in a fine-grained, dark greenish-grey, felted groundmass.

All of the porphyritic spessartites in the tunnel have been metasomatised, some much more than others. In them, hornblende is often partially replaced by epidote. Secondary minerals are quartz, epidote, chlorite, muscovite, pyrite and occasional siderite.

The porphyritic spessartite from 2,435 feet in the tunnel contains occasional large, clear, zoned and twinned oligoclase crystals. These have obviously been picked up from the granodiorite during dyke intrusion, and are therefore of xenocrystic character, like alien crystals recorded in lamprophyres by Doss (1890, p. 27), by Harker (1892, p. 200), by Reynolds (1931) and by Smith

(1933 and 1936). It is therefore not uncommon to find minerals of accidental origin in lamprophyres.

Occurrences of quartz in the Bogong lamprophyres are of two types (a) xenocrystic, and (b) secondarily introduced from solutions. Those of xenocrystic origin are sometimes partially embayed, those of secondary origin (from solutions) are often ringed with epidote and chlorite which have been pushed aside during the growth of the quartz.

Camptospessartite. This forms a dyke 30 feet wide between 655 and 685 feet in the tunnel. The rock is porphyritic with phenocrysts of labradorite in a fine-grained, dense, dark groundmass containing small laths of andesine. Green patches in the rock are chloritic with associated actinolite and tremolite, minerals that were formed by the hydrothermal alteration of pyroxene. Similar aggregates of tremolite after pyroxene have been noted by Macgregor (1937, p. 467), and Junner (1921) noted actinolitic and tremolitic outgrowths on hornblende in diorite porphyrites and lamprophyres from the Wood's Point-Walhalla district in Victoria. Iron ore minerals are common in the Bogong camptospessartite. Ferromagnesian minerals are represented by both brownish coloured hornblende, typical of the more basic types of igneous rocks, and greenish coloured hornblende, typical of less basic rocks. Quartz is wanting, and the characteristic secondary minerals are chlorite, epidote, zoisite and pyrite.

On the basis of the presence of some brownish coloured hornblende and more frequent basic plagioclase phenocrysts than occurs in the spessartites, it is apparent that this dyke is a more basic phase than spessartite and approaches camptonite in mineralogical composition. Augite, however, which is typical of camptonite, is not present, unless certain patches of secondary minerals represent original augite. The available evidence indicates that the rock is an intermediate type between camptonite and spessartite, and is therefore referred to as camptospessartite.

Augite Lamprophyres. The 4 to 6 feet wide dyke at 3,155 feet is closer to camptonite in mineral composition. Normally, camptonite differs from spessartite in possessing purple augite, brown hornblende and occasionally a residuum of analcite which often segregates in spots or 'ocelli,' it resembles the lamprophyres in its panidiomorphic crystallisation. In the No. 3 Tunnel sample, pale purple augite, basic plagioclase, iron ore minerals and chlorite are present, but no brown hornblende, so the rock is referred to as augite lamprophyre. Some of the chlorite is associated with serpentine in spherulitic growths and as alteration products of olivine, like examples described by Smith (1933) and by Poitevin and Cooke (1946). Calcite and sulphide minerals are present, indicating some degree of metasomatism.

A more altered, porphyritic augite lamprophyre dyke (1½ inches wide) obtained from the tunnel dump, represents metasomatised camptonite. The edges of the dyke (Pl. XVIII A) are fine-grained and free of phenocrysts, but the central portions are crowded with basic plagioclase phenocrysts, characteristically containing sieved masses of the chloritic groundmass. Each phenocryst is enveloped by a clear rim of optically continuous plagioclase and has associated secondary white mica and zoisite. Other phenocrysts in the rock are much altered and consist of masses of bladed talc crystals and tremolite in a greenish-coloured, isotropic base. These phenocrysts represent completely altered hornblende or olivine crystals (cf. Richey, 1939, p. 410). Occasional eight-sided cross sections of partially altered augite are also present, some with small amounts of greenish-brown biotite (cf. Morrison, 1918, p. 134). The groundmass felspars consist of basic plagioclase laths, and they occur in a greenish-coloured, dusty matrix containing ilmenite.

Monchiquite. The term monchiquite has been used in Victoria for certain basic dykes occurring in the Central Victorian goldfields (Stillwell, 1912), and for others associated with the Older Volcanic (Tertiary) basalt flows (Jacobson, 1937 and Edwards, 1939). The Bogong examples are not quite the same as these monchiquites in texture or mineralogical composition, and are associated in space and probably petrologically with the dioritic lamprophyres of the Bogong area. They are best regarded as felspar-free, basic lamprophyric dykes, more basic than the camptonite group. They are more crystalline than the monchiquites associated with the Older Volcanic (Tertiary) series in Victoria. They do not have analcite, or hornblende or iddingsite altering from olivine, like many of the Tertiary dykes, and since they show evidence of having been sheared along with the other melanocratic dykes cutting the granodiorite at Bogong, they pre-date shear and metasomatism in this area, and are presumably much older than the Tertiary monchiquites in Victoria.

Narrow dykes of monchiquite, varying from 6 to 12 inches wide, are comparable in width to the majority of the monchiquite dykes in the Bendigo goldfield (Stillwell, 1912). They are of dense texture and show a microporphyritic panidiomorphic texture. The microphenocrysts consist of altered olivine and occasionally augite. The groundmass is composed of numerous laths of pale purple to colourless augite, abundant grains of iron ore minerals and some glass. Secondary calcite is of amygdaloidal character in parts. One grain of picotite was observed.

The edge of the monchiquite dyke at 3,455 feet is much denser than central portions, indicating chilling in contact with the granodiorite. Numerous minute cavities in parts of the edge of the dyke, sometimes contain isotropic material fringed with birefringent fibres, forming structures resembling ocelli (cf. Smith, 1936, p. 368, and Boulton, 1911, p. 468). Some of the cavities have calcite centres.

The 6 inches wide monchiquite dyke at 2,495 feet splits into narrower branches, and has been subjected to considerable alteration. Pseudomorphs of calcite and chlorite after olivine crystals (some corroded) and after augite laths, are common. They are set in a fine-grained chloritic groundmass containing abundant iron ore dust. Veins of calcite traverse the rock in many directions.

Shear and Metasomatism

All types of rocks forming the walls of No. 3 Tunnel, have been subjected in parts to either shear or metasomatism or both.

METASOMATISM

The effects of metasomatism on the granodiorite and various dyke rocks have been outlined in references to hydrothermal alteration under the sections dealing with the several rock types.

Junner (1921) has shown that the narrow dykes of hornblende and biotite lamprophyres that frequently accompany auriferous quartz reefs in Victoria, are without exception more or less hydrothermally altered. Occasionally the alteration is so intense that the original characters of some of these dykes are indeterminate, and the alteration products characteristic of propylitisation are never entirely absent. The same applies at Bogong, in No. 3 Tunnel, where the principal effects of metasomatism have been—

(i) partial bleaching of constituents in certain zones of the granodiorite, with the consequent formation of several colour varieties.

(ii) chloritisation, epidotisation and sericitisation of the ferromagnesian constituents in the granodiorite and in some of the less basic of the melanocratic dyke rocks.

(iii) chloritisation and serpentinisation of the ferromagnesian constituents of the more basic dyke rocks, with accompanying development of actinolite, tremolite and talc in parts of some of these dykes.

(iv) saussuritisation of the felspars of all rocks containing primary felspars that were subjected to the chemical activity of metasomatic solutions, leading to the formation of zoisite, clinozoisite and secondary white mica.

(v) calcification of both the amphiboles and pyroxenes and of certain of the felspars in the dyke rocks.

(vi) introduction of pyrite and pyrrhotite in altered zones of the granodiorite and in most of the less basic of the melanocratic dyke rocks.

(vii) introduction of secondary quartz in parts of the granodiorite and some of the altered dyke rocks.

The processes producing hydrothermal alteration represent the final stages of igneous activity in the No. 3 Tunnel area. During the process residual carbonate-bearing solutions invaded the various igneous rocks, resulting in mineral alteration and partial replacement by juvenile reactions.

SHEAR

In several parts of the tunnel, evidence of shear involving all the rock types present, is provided by the occurrence of pug seams, slickensided joint surfaces and numerous planes of movement of small amplitude. The zones so affected are indicated by the letters S. and S.M. in Fig. 2. At 4,025 feet, a shear zone 6 inches to 1 foot wide, follows a flat-lying joint plane, indicating the development of horizontal as well as steeply dipping to vertical shear zones.

Minor amounts of shear can also be noted in thin sections of some of the rocks. In the metasomatised camptonite (Pl. XVIII A) from the tunnel dump, a small shear zone through the central parts of the dyke, shows little lateral displacement but marked granulation of the minerals. Another small shear zone at the edge of this dyke, traverses both the metasomatised camptonite and the adjacent granodiorite. Metasomatised portions of the granodiorite occasionally reveal strain effects in quartz crystals in thin sections. In the contact between the spessartite dyke and the granodiorite at 2,435 feet in the tunnel, several small shear planes in the granodiorite trend parallel to the dyke walls, and the more brittle minerals in the granodiorite near the junction with the dyke have been granulated, while biotite has been contorted. The parallel shear planes also possess granulated minerals.

Shear planes are numerous and closely spaced in the 16 feet wide dyke of spessartite at 3,415 feet. Generally, however, the melanocratic dykes have not been strongly sheared and crushed (cf. Tomkeieff and Marshall, 1940). Shear planes are also well developed in contaminated granodiorite adjacent to the leucocratic dyke near the tunnel entrance, and in the monchiquite dyke and nearby granodiorite at 3,365 feet.

The final phases of shear and metasomatism involved the introduction of calcite, veins of which cut spessartite at 1,135 feet and monchiquite at 3,365 feet. A calcite vein $\frac{3}{4}$ inch wide, found on the tunnel dump, bifurcates through metasomatised granodiorite. Some of the quartz veins, varying from $\frac{1}{2}$ to $1\frac{1}{2}$ inches wide, were also injected during the end stages of shear and metasomatism.

Jointing

Joint planes in the granodiorite were best seen at the north end of the tunnel, between the surge tank and the rise (Fig. 2). Here, closely spaced, more or less flat-lying joints have maximum dips of 8°. Steeply inclined joint planes, approximately at right angles to the flat-lying joint planes, occur in several intersecting sets. Three sets were most marked, striking in approximately the same directions as the majority of the dyke rocks in the tunnel, and dipping at 80°. Flat-lying joints at 3,915 feet trend east-west, and similar joints at 3,415 feet, pass through both the granodiorite and the 16 feet wide dyke of spessartite, indicating that they are tectonic joint planes, rather than due to shrinkage on cooling.

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Descriptions of Plates

PLATE XVIII

A—Jacketed felspars crowded in centre of narrow dyke of augite lamprophyre (probably metasomatised camptonite). Dyke has fine-grained, chilled edges and cuts through fine-grained granodiorite. (x 0.75).

B—Leucocratic vein cutting contaminated granodiorite from near south end of tunnel. Flow planes shown by orientation of biotite plates. Shear planes in contaminated granodiorite and dyke rocks are largely parallel to the walls of the dyke. (Natural size).

C—Sheared and metasomatised granodiorite (Natural size).

D—Basic schlieren. Darker areas consist of partially granitised gneiss. (x 0.75).

PLATE XIX

Contact of augite lamprophyre (probably metasomatised camptonite) and granodiorite. Showing veinlet of dyke rock intruded at an acute angle to the walls of the dyke, and zone of shear formed in the granodiorite ahead of the veinlet. (x 10).

(Photos. by Miss M. L. Johnston)